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Negative magnetoresistance and hole-hole interaction in multilayer heterostructures p-Ge/Ge$_{1-x}$Si$_x$

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Abstract. The quantum corrections to the conductivity of the high-mobility multilayer p-Ge/Ge$_{1-x}$Si$_x$ heterostructures are investigated at $T = (0.1 \div 20)$K in magnetic fields B up to 1.5 T. The observed negative magnetoresistance with logarithmic dependencies both on temperature and magnetic field for $B > 0.1$ T is interpreted as the consequence of the particle-particle (hole-hole) attractive interaction in the Cooper channel. Out of the interaction constant value $g(T) = (\ln T_C/T)^{-1}$ the effective temperature of superconducting transition is estimated: $T_C \leq 0.03$ K.

Introduction

The diffusive nature of electron motion in disordered conductors results in quantum corrections to the transport effects with nontrivial dependencies on temperature T and magnetic field B [1, 2]. These corrections are of the order of $(k_F l)^{-1}$ where k_F is the Fermi quasimomentum and l is the impurity scattering length. The total quantum correction consists of the single-particle weak localization part and the part due to disorder-modified electron-electron (e-e) interaction between particles with close momenta and energies (in diffusion channel) and between particles with small total momentum (in Cooper channel). All three quantum corrections, i.e., localization, e-e interaction in the diffusion channel and e-e interaction in the Cooper channel lead to the logarithmic low-temperature dependence for the conductivity at $B = 0$.

The different quantum corrections may be separated by the application of an external magnetic field as each quantum effect has its own range of characteristic magnetic fields. In the absence of spin scattering the magnetoresistance associated with the weak localization is negative. For this effect there exist two characteristic fields: the field B_φ of crossover from parabolic to logarithmic B — dependence of magnetoresistivity ($B_\varphi = \hbar c/4eL_\varphi^2$, L_φ — being the inelastic scattering length) and the field $B_{tr} = \hbar c/2el^2$, where the magnetic length become less than the elastic scattering length. Beyond the diffusion approximation at $B \gg B_{tr}$ the effect of weak localization is suppressed in a great extent [3, 4].

For the correction $\Delta\sigma$ to the conductivity due to e-e interaction in the Cooper channel we have [5]

$$\Delta\sigma(B) - \Delta\sigma(0) = -\frac{e^2}{2\pi\hbar} g(T)\varphi_2(x) \quad (1)$$

where $\varphi_2(x) = \ln x$ for $x \gg 1$ and $x = B/B_{\rm int}$ for $B < B_{\rm s}$, $x = B/B_{\rm s}$ for $B > B_{\rm s}$. Here $B_{\rm int} = \pi\hbar c/2eL_T^2$ ($L_T^2 = \hbar D/kT$, D being the diffusion constant) and $B_{\rm s} = \pi kT/g\mu_B$ are the characteristic fields for orbital and spin effects, and $g(T)$ is the effective interaction constant of two particles with the opposite momenta: $g > 0$ for repulsive interaction and $g < 0$ for attractive interaction due to virtual phonon exchange. In the latter case $g(T) = (\ln T_C/T)^{-1}$ where T_C is the superconducting transition temperature and expression (1) is valid for $T > T_C$. For the relation of the orbital and spin effects we have

$$B_{\rm s}/B_{\rm int} = 2(k_{\rm F}l)(m_0/mg). \tag{2}$$

The interaction contribution in the diffusion channel is not sensitive to the magnetic field until the spin splitting become important at $B > B_{\rm s}$ [2]. The corresponding magnetoresistance is proportional to the constant of direct Hartree interaction and should be positive.

1 Results and discussion

We have investigated the quantum corrections to the conductivity and magnetoconductivity of 2D hole gas in strained multilayer p-Ge/Ge$_{1-x}$Si$_x$ ($x = 0.03$) heterostructures at $T \geq 0.1$ K in magnetic fields up to 1.5 T. With the hole densities $p = (2.4 \div 2.6)\cdot 10^{11}$ cm^{-2} and mobilities $\mu = (1.0 \div 1.7)\cdot 10^4$ cm^2/Vs we have a good metallic conductivity on Ge layers: $k_F l = (10 \div 20)$. For the Ge layer width $d = 200$ Å the motion of holes in transverse direction is quantized, only one confinement band to be occupied: $k_{\rm F}d/\pi \approx 0.8$. The conductivity at $B = 0$ decreases with temperature decrease and varies as the logarithm of T in a wide temperature range $(0.1 \div 20)$ K (Fig. 1).

Figure 2 shows the effect of negative magnetoresistance in a whole range of the classically weak magnetic fields $\omega_c\tau < 1$ ($B < B_c$, where $B_c = mc/e\tau$) at different temperatures. The magnitude and T dependencies of the characteristic magnetic fields B_φ, $B_{\rm tr}$, $B_{\rm int}$, $B_{\rm s}$ and $B_{\rm c}$ for one of the investigated samples ($p = 2.4\cdot 10^{11}$ cm^{-2},

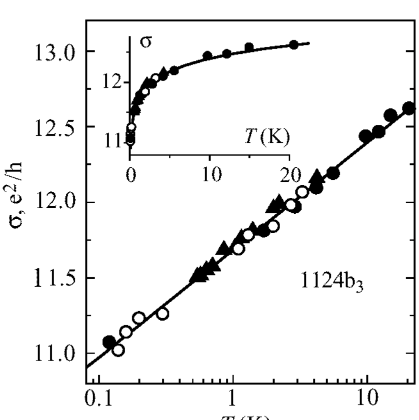

Fig 1.

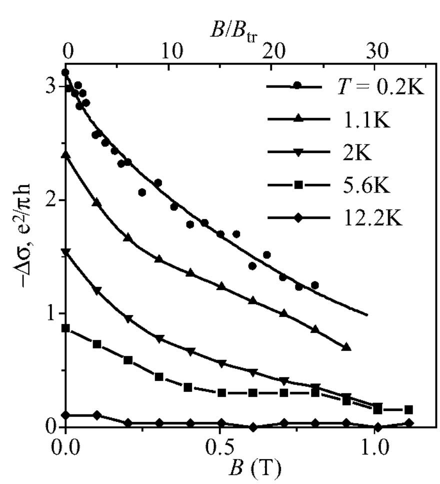

Fig 2.

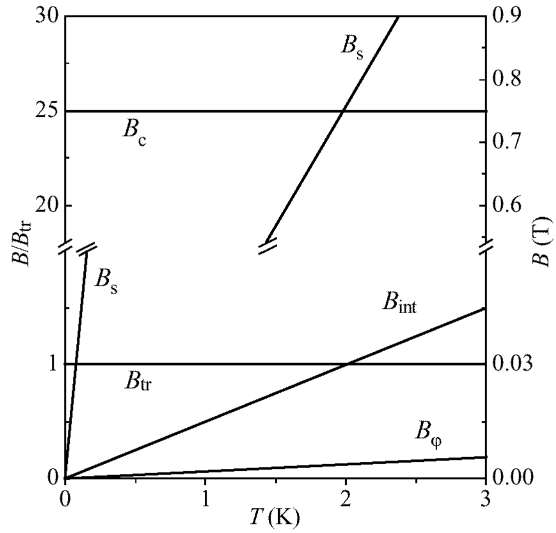

Fig 3.

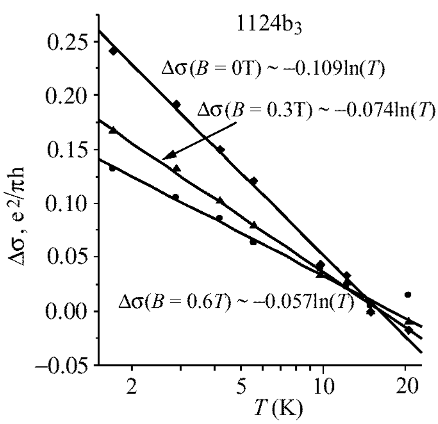

Fig 4.

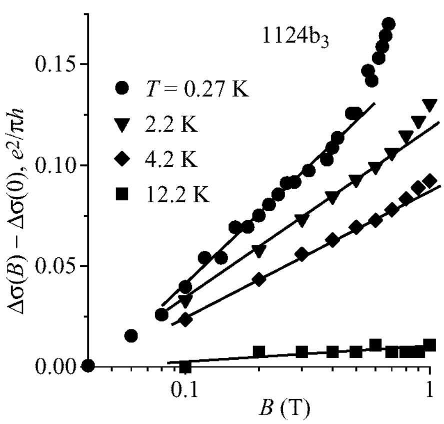

Fig 5.

$\mu = 1.0 \cdot 10^4$ cm^2/Vs, $k_F l = 12.4$, $l = 1 \cdot 10^{-5}$ cm, $B_{tr} = 0.03$ T) are presented on the diagram of Fig. 3. Here the relations $B_c = 2(k_F l)B_{tr}$ and $B_s = 2(k_F l)B_{int}$ are used (for the strained Ge valence band the spin splitting is about the half of the cyclotron one [6] and in Eq. (2) $m_0/mg \approx 1$).

Due to a high mobility of holes only a small magnetic field B_{tr} is needed to suppress the effect of weak localization. The logarithmic dependence of $\Delta\sigma$ on T at $B \gg B_{tr}$ (Fig. 4) unambiguously is the evidence of the quantum correction associated with e-e interaction. As the magnetoresistance observed at $B > 10B_{tr}$ is still negative we assume that this range of B shows preferentially the effect of the particle-particle interaction in the Cooper channel (1) with $g(T) < 0$ (attraction of holes with opposite momenta). In accordance with Eq. (1) the logarithmic dependencies of $\Delta\sigma$ on magnetic field is observed between 0.1 and 1 T (Fig. 5). On the $B - T$ diagram of Fig. 3 it may be seen that in this interval of B ($3 \leq B/B_{tr} \leq 25$) for $T > 2$ K only the orbital effect in the Cooper channel is important ($B_{int} < B < B_s$). For $T < 2$ K both effects are actual and for sufficiently low temperature spin effect dominates ($B > B_s$). A fit of the magnetic field dependence gives $|g(T)| = 0.018\pi$ at $T = 0.27$ K which corresponds to superconducting temperature $T_c \approx 0.03$ K. It is only the upper limit for T_c as, in principle, at $B > B_s$ the positive magnetoresistivity due to the spin splitting of the triplet state in the diffusion channel should also take place. In the presence of the latter contribution the true magnetoresistivity in the Cooper channel expected to be more negative than the observed one.

2 Conslusions

The observations of the magnetoresistance due to e-e interaction in the diffusion channel were reported for high mobility GaAs/AlGaAs heterostructures [7] and for MBE grown doped GaAs [8]. The positive part of the magnetoresistance for the electron gas in the short-period Si/SiGe superlattices was assigned both to the spin splitting in the diffusion channel and the e-e repulsion in the Cooper channel [9]. Moreover, due to the relatively short escape time from one well into another only anisotropic 3D (not 2D) version of theory was able the describe the experimental data. Our study of the negative magnetoresistance in p-Ge/$Ge_{1-x}Si_x$ heterostructures clearly demonstrates the wide intervals of temperature and magnetic fields where the quantum correction is dominated by the hole-hole attraction in the Cooper channel.

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References

[1] Lee P. A. and Ramakrishnan T. V., *Rev. Mod. Phys.* **57** 287 (1985).
[2] Altshuler B. L. and Aronov A. G. in *Electron-Electron Interactions in Disorder Systems*, Amsterdam, 1985 p.1.
[3] Hikami S., Larkin A. I. and Nagaoka Y. *Progr. Theor. Phys.* **63** 707 (1980).
[4] Dyakonov M. I. *Sol. St. Commun.* **92** 711 (1994).
[5] Altshuler B. L., Aronov A. G., Larkin A. I. and Khmelnitskii D. E., *Zh. Eksp. Teor. Fiz.* **81** 768 (1981).
[6] Gorodilov N.A., et al. *Pis'ma Zh. Eksp. Theor. Fiz.* **56** 409 (1992).
[7] Choi K. K., Tsui D. C. and Palmaateer S. C., *Phys. Rev. B* **33** 8216 (1986).
[8] Poirier W., Mailly D. and Sanquer M. *Cond-mat/9706287.*
[9] Brunthaler G., Dietl T., Sawicki M., Stoger G., Jaroszynski J., Prinz A., Schaffler F. and Bauer G. *Semicond. Sci. and Technol.* **11** 1624 (1996).